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ABSTRACT

Seventy-two students enrolled in elementary science education methods courses participated in a study designed to reveal student views about the nature of science prior to, during, and upon completion of the course. The course employed various teaching approaches and activities to help students develop more adequate views about the nature of science. An attempt was also made to help students relate what they learned in their methods class about the nature of science to the teaching of elementary science. The Modified Nature of Scientific Knowledge Scale (MNSKS), developed by Y. Meichtry (1992) was used to measure and compare student views about four dimensions of the nature of scientific knowledge at the beginning and end of the semester. Results indicate that students begin their methods courses with understandings of the nature of science which are largely incomplete. It also indicates the potential of developing much more complete understandings about the nature of science as a result of integrating teaching strategies. Five tables and one figure illustrate study data. Contains two references. (ZWH)

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ED 382 448

Elementary Science Methods

Strategies to Measure and Develop Student Views About the Nature of Science

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AETS Annual Meeting
January 5-8, 1995
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Symposium: The Nature of Science in Science Teacher Education

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Introduction

During a one-semester, 3 credit hour elementary science methods course, strategies were used with each of three sections taught, to reveal student views about the nature of science prior to, during, and upon completion of the course. Various teaching approaches and activities were integrated within the course to help students develop more adequate views about the nature of science. In addition to strategies designed to develop understandings about the nature of science, an attempt was made to help these students relate what they learned in their methods class about the nature of science to the teaching of elementary science.

The nature of science, as defined in this paper, is characterized by the two areas of the nature of scientific inquiry and the nature of scientific knowledge. Scientific inquiry is described, in general terms, as processes used to generate and test scientific knowledge. The nature of scientific knowledge is defined as developmental (tentative), testable (capable of empirical test), creative (partially a product of human creativity), and unified (the specialized sciences contribute to an interrelated network of laws, theories, and concepts).

Although there is a distinction made between these two areas of the nature of science for purposes of discussion, the interdependent nature of these two areas is made evident. The study of the nature of science throughout the semester was addressed through the broader context of scientific literacy.

Description of Course and Student Population

During the three sections of a one-semester elementary science methods course, students received direct classroom instruction for a period of 12 weeks and completed 4 weeks of field experience in the schools. The class met for a period of 75 minutes, twice weekly.

Major course requirements and experiences included the following: 1) daily hands-on, inquiry learning, 2) teaching a learning cycle lesson to peers and to elementary students, 3) conducting a controlled research experiment involving observations made over time, writing a research report, and sharing results with peers, 4) field assignments which involved teaching science, interviewing children for a variety of purposes, and describing science programs used in schools and classrooms, 5) development of a unit which integrated science with other subject areas, 6) quizzes and a final exam. Following several of these experiences, students were required to summarize their reflections about what they learned about science and science teaching.

There were 72 students total in the three sections of science methods. Students enrolled in this methods course are college seniors and graduate students who are seeking teacher certification. The college seniors take this course as part of a block of five methods courses. The vast majority of these students take the methods block the semester before student teaching.

Science content coursework, at minimum, taken prior to the science methods course consists of a 4-credit biology course taught by Arts and Sciences faculty and two, 4-credit physical science courses taught by science education faculty specifically for elementary

education majors. Each of these three science courses has a laboratory component.

Methodology

Teaching Strategies Used to Develop More Adequate and Complete Views of the Nature of Science

Strategies to develop more accurate conceptions of the nature of science were integrated throughout the semester in the context of scientific literacy. A constructivist approach was used by providing students with a common, first-hand experience upon which they constructed their own understandings about the nature of science. Topics related to the nature of science were not discussed by the instructor until students first had the opportunity to construct their own understandings.

The strategies used include the following: 1) learning cycle lessons taught to peers and to elementary students (including a reflective analysis about what was learned about science and science teaching), 2) interviews conducted with elementary students about their definition of science and description of what scientists do (including a summary of what was learned about children's perceptions of science), 3) the conduct of a long-range experiment, a written research report, and sharing of results with peers, 4) a follow-up reflective analysis of the long-range experiment, summarizing what was learned about the nature of scientific inquiry and how such an experiment might be structured in an elementary classroom, 5) a quiz on the nature of science, and 6) the examination of verification and inquiry-based lab experiences and the language used in text passages

and exams in the context of teaching elementary students about the nature of science.

Emphasis throughout all activities, with the exception of the reflective analyses, was placed on the inquiry process of generating knowledge, the developmental, testable and creative nature of scientific knowledge, and the scientific attitudes and values of objectivity, openness, importance of basing conclusions on scientific evidence, intelligent "failure", and the social context of science. Instructions for the reflective analyses following several of the experiences were consistent with the constructivist approach in that students were provided with open-ended questions, which allowed them to construct and synthesize their own learning.

Strategies to Relate Learnings About the Nature of Science With Teaching Elementary Science

The class period during which students submitted their written research report (see attached guidelines in Appendix A) and made an oral presentation of their research study to classmates, they were given a follow-up written assignment to be due the following class period. This follow-up assignment required students to summarize the individual learning that occurred as a result of conducting the long-range experiment by answering the following two questions 1) What did you learn about the nature of scientific inquiry as a result of conducting this experiment? and 2) What are your ideas about structuring long-term experimentation and observation with elementary students?

The questions and instructions provided for this summary were open-ended. The intent of the instructor, employing a constructivist

approach, was to assess learning about the nature of science "constructed" by students as a result of actually using the scientific inquiry process. For that reason, the students were asked to respond to the two questions immediately upon completion of the experiment, written report and oral presentation with as little guidance from the instructor as possible.

Strategies Used to Measure Student Views About the Nature of Science

Several strategies were used to reveal student conceptions about the nature of science throughout the semester. Strategies were used to measure student views on the first and last day of class, as well as views which had evolved during different times of the semester. The intent was to determine the extent and nature of change in student views about the nature of science and science teaching as a result of different classroom experiences and as a result of combined classroom experiences during the semester.

Qualitative measures: Pre- and post-semester. Students were asked to respond to the following two questions on the first and last day of class: 1) What is science? and 2) How do you think science should be taught at the elementary level? After students responded to these two questions on the last day of class, they were provided by the instructor with the responses they wrote on the first day of class. They were then asked to review both responses and write a description of the differences between the two responses. Next they were asked to write an account of what they perceived to be the cause of the differences, in the context of classroom experiences they had during the semester. The purpose of this measure was to provide the instructor with insights about the extent to which students could

identify changes in their views and classroom experiences which caused a shift in their views.

Quantitative measure: Pre- and post semester. The Modified Nature of Scientific Knowledge Scale (MNSKS), developed by Meichtry (1992), was used in this study to measure and compare student views about four dimensions of the nature of scientific knowledge at the beginning and end of the semester. This instrument is a modified version of the Nature of Scientific Knowledge Scale (NSKS), developed by Rubba and Anderson (1978). The four dimensions of scientific knowledge measured were the developmental nature (scientific knowledge is tentative), testable nature (scientific knowledge is capable of empirical test), creative nature (scientific knowledge is partially a product of human creativity), and unified nature (the specialized sciences contribute to an interrelated network of laws, theories, and concepts).

The MNSKS was administered as a pre-test on the first day of class after students had responded to the questions "What is science" and "How should science be taught at the elementary level?". The MNSKS was administered as a post-test on the last day of class after students had responded to the same two questions.

Each of the four dimension of the nature of scientific knowledge were represented on the MNSKS as subscales. A total of 32 statements (8 for each subscale) were presented in a Likert Scale response format containing five choices (strongly agree to strongly disagree).

Qualitative measure: Long-range experiment. To assess what students had learned about the nature of scientific inquiry and the nature of scientific knowledge, and the extent to which students

related these learnings to the teaching of elementary science, a long-range experiment follow-up summary was completed by each student. The students were asked to respond in writing to the following two questions: 1) What did you learn about the nature of scientific inquiry as a result of conducting this experiment? and 2) What are your ideas about structuring long-term experiments and observation with elementary students?

Results

Reliability of MNSKS

The reliability coefficient alphas reported in Table 1 were obtained from students' pre-test scores on the MNSKS. The reliabilities of the four subscales (developmental, testable, creative, and unified) ranged from .69 - .83 and was .76 for the overall instrument.

Pre-Semester Student Views

Description of statistical data. In addition to an overall score on the MNSKS, mean scores for each of the four subscales (developmental, testable, creative, and unified) were obtained. Respondents received from one to five points on each of the 32 items. The more consistent a respondent's viewpoint is with the premise of each subscale, the higher will be the score. Subscale scores which are arithmetically higher than 24 and overall scores higher than 96, are in the direction of the currently accepted view of the nature of scientific knowledge, while scores lower than these are indicative of conceptions which are inconsistent with currently accepted views.

The means of student responses for each subscale and the overall score of the MNSKS on both the pre- and post-test are presented in

Table 2. The mean scores of students on the pre-test ranged from 29.7 - 33.8 for the four subscales and was 125.8 for the overall instrument. Post-test mean scores of the subscales ranged from 31.4 - 35.2 and was 132.3 for the overall instrument.

An examination of these mean scores provide evidence that student views were in the direction of currently accepted views of the developmental, testable, creative, and unified nature of scientific knowledge at both the beginning and end of the semester. In addition, the mean scores on the post-test were higher than the mean scores on the pre-test for each of the four subscales as well as the overall instrument, indicating an increase in student understanding of the nature of scientific knowledge during the semester.

Comparative results of statistical analysis. To determine whether the post-test mean scores of each of the four subscales of the MNSKS and the overall instrument differed significantly from pre-test mean scores, a paired comparison t-test analysis was conducted. To determine statistical significance at the .05 level, t statistics were calculated using the SAS PROC MEANS PROGRAM.

The results of the paired comparison t-test analysis, presented in Table 3, indicated that the increase in student understanding of the nature of scientific knowledge during the semester was statistically significant. The t statistic for each of the four subscales and the MNSKS were significant at the 0.001 level.

Comparison of Pre- and Post-Semester Student Views

The questions "What is science?" and "How should science be taught to elementary students?" were asked on the first (pre-response) and last day of class (post-response). The views related to both

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questions for the pre- and post-responses were listed in order of frequency and categorized into the two broad areas of "science as a body of knowledge" (content focus) and "science as a process used to generate scientific knowledge" (process/inquiry-oriented). Sub-categories of content and process responses were developed to characterize more specifically the learning of students related to the various science inquiry processes and multi-dimensional nature of scientific knowledge.

Comparisons were then made between the number and type of responses related to science content and science process on the pre- and post-responses. More specific views about the developmental, testable, and creative nature of science, as defined by the MNSKS, were listed and compared. The degree to which understandings related to the developmental, testable, and creative nature of scientific knowledge increased were compared to the results of the statistical analysis of these understandings as measured by the corresponding subscales on the MNSKS.

The post-class responses to the questions "What is science?" and "How should science be taught to elementary students?" revealed that students developed a much more complete understanding of the nature of science inquiry throughout the semester. There was evidence that student understandings of the developmental, testable, and creative nature of scientific knowledge were also developed, although to a lesser degree.

<u>What is science? Comparison of pre-and post-response</u>. Student views revealed on the first day of class about what science is and how science should be taught at the elementary level, heavily emphasized

the knowledge base of science. Their views about the processes of science were largely incomplete. Sixty-nine responses to the question "What is science?" were content-oriented compared to 39 process-oriented responses. Thirty-five of the 69 content-oriented responses said simply "the study of our world". Although there was only a slight reduction in the number of responses related to science as a body of knowledge from pre- to post-response (from 69-63), thirteen of the content post-responses distinguished the branches of science as physical, life, and earth, which was a response absent from the pre-response. Pre-and post-responses which related to science content included the environment around you, the branches of science, use of fact, theories, and laws, way of describing world, physical and abstract view of world, an answer to many questions, and core subjects dealing with both known and unknown factors.

Most importantly, the number of student responses which related to science as process increased from 39 on the pre-response to 77 on the post-response. Examples of process-oriented responses include a way of thinking about problems and curiosities, a method of discovery, an organized process in which ideas are tested, conducting an experiment to test a hypothesis, science is ever-changing and growing with new information, systematic approach to obtain knowledge, involves repeated trials, science is an ever-changing experience, discovery-inquiry-exploration, and going through a process that involves thinking and may involve attitudes and values.

One area of response which distinguished pre- and post-responses was that many post-responses referred to specific scientific processes such as observation, questioning, hypothesizing, various aspects of

experimental methodology, and drawing conclusions, while pre-responses did not. Furthermore, the ability of students to define and understand the importance of these processes was much more evident in post-responses.

The relationship of responses to the developmental, testable, creative, and unified nature of scientific knowledge increased from pre- to post-response. There were 12 additional responses to the question "What is science?" that related specifically to the development nature of scientific knowledge, 4 to the creative nature, 2 to the testable nature, and one to the unified nature of scientific knowledge. Responses related to the creative and unified nature of scientific knowledge were absent from pre-responses.

How elementary science should be taught: Comparison of pre- and post-response. There was a significant decrease in the number of content-oriented responses between pre- and post-response which related to how elementary science should be taught. Forty seven pre-responses emphasized the importance of teaching science content compared to 18 post-responses. Although 28 of the 47 pre-responses related to teaching science content identified using a hands-on approach, the emphasis was placed on using hands-on methods to help elementary students better understand content rather than the processes of science. Examples of content-oriented responses included how science affects students, teaching basic facts, understanding vs memory, teaching of concepts sequentially, and teaching about animals, habitats, substances, etc.

The number of responses which related directly to teaching about the nature of science increased from 13 to 27 from pre- to post-

response. Examples of responses which related to the nature of science included the following: teach basic methods of discovery, teach and apply scientific method, hands-on learning for the purpose of teaching process, as a process to gain knowledge, finding answers to self-questions, design own means of solving problems, and allow students to test theories.

Of significant importance is the increase in the number of responses that were more vaguely related to the nature of science, such as discovery, inquiry, student-centered, critical thinking, exploration, experimentation, and use of learning cycle. The number of these types of responses increased from 41 on the pre-response to 121 on the post-response. Although the direct relationship between these types of teaching approaches and teaching the nature of science was not made explicit by students, this relationship is implicitly evident.

Pre-responses related to the developmental, testable, creative, and unified nature of scientific knowledge were limited. Only one response related to the developmental and testable nature of scientific knowledge. Post-responses related to the developmental and testable nature of science increased only slightly from one to 6 and from one to two respectively. Ideas related to the creative and unified nature of scientific knowledge were absent on both the pre-and post-response.

Differences in Pre- and Post-Responses Identified by Students

After comparing their pre-and post-responses on the last day of class, students described any differences they noted between their responses. The differences noted by students were listed, counted,

and compared to the type and number of different responses noted by the instructor. These differences were related to the nature of scientific inquiry and to the developmental, testable, and creative nature of scientific knowledge.

Analysis of student descriptions of the differences between their pre- and post-responses and the comparison of this analysis with differences noted by the instructor revealed that while some students were able to explicitly identify differences in relationship to the nature of science, others were not. Sixteen differences (related to the nature of science) to the question of "What is science?" were noted by students, compared with 53 differences noted by the instructor. To the second question, "How should science be taught at the elementary level?", the students noted a total of 27 differences compared to 38 differences identified by the instructor.

The number of students who included more information about the nature of science in their post-test response was significant. Forty seven of 77 students (61%) wrote post-responses to the question "What is science?" which were more related to the nature of science and 34 of 77 students (44%) included more information related to the nature of science in their post-response to the question "How should science be taught at the elementary level?" The lesser degree to which students included responses related to the nature of science in response to the question of how science should be taught at the elementary level indicates that students may not necessarily relate their learnings about the nature of science to the teaching of elementary science.

Classroom experiences identified by students that caused a positive change in their pre- and post-responses were not very helpful to the instructor in regard to providing insights about the extent to which students could identify classroom experiences which caused a shift in their views. Most of the students spoke in general terms about classroom experiences that affected their post-responses rather than relating specific classroom experiences to specific learnings. The following types of responses were typical: 1) "The classroom experience of discovery made my response to number one different" and 2) "Having been in the classroom and teaching the peer lesson, I know more approaches that can be used to teach science".

Long-Range Experiment Follow-Up: Student Reflection

Student responses to the two questions "What did you learn about the nature of scientific inquiry as a result of conducting this experiment"? and "What are your ideas about structuring long-term experimentation and observation with elementary students?" were listed in order of frequency and categorized according to various science inquiry processes and different dimensions of the nature of scientific knowledge. The degree to which the understandings developed by students related to the developmental, testable, and creative nature of scientific knowledge increased were compared to the results of the statistical analysis of these understandings as measured by the corresponding subscales on the MNSKS.

One area of interest to note is that several students volunteered the information that the experience of conducting a long-range experiment was their first ever. One student said it was his second experience, the first being a 7th grade science fair project.

Student learning about scientific inquiry. Responses to the question of what was learned about the nature of scientific inquiry overwhelmingly revealed a greater depth of student understanding, and in many cases, the development of a more positive attitude toward the usefulness of scientific inquiry. Although the number of students who explicitly said that they had developed a greater understanding of scientific inquiry as a result of conducting the long-range experiment was 27, it was evident that all 69 respondents acquired a greater understanding. Examples of student responses are presented in Figure 1.

Responses indicated an increased understanding related to the developmental, testable, creative, and unified nature of scientific knowledge, in respective order of frequency. The number of responses related to each dimension of science are presented in Table 4. The categorization and frequency of other areas of science inquiry in which learning increased as a result of conducting the long-range experiment are summarized in Table 5.

An area of positive change that occurred as a result of students conducting the long-range experiment that is not reflected by Figure 1 or Tables 4 and 5, concerns an internal shift in student belief systems that is very important to understanding the nature of science. Many of the students described a shift in feelings from initially being very disappointed by having to reject their hypothesis to feelings of "it's really of if the hypothesis is rejected". One student even said she was glad her hypothesis was rejected because of what she learned!

Student learning about the conduct of long-range experimentation with elementary students. Although many responses to this question related to areas of learning not directly related to the nature of science, such as structure of student groups and time issues, there were numerous and varied responses related to the nature of science. First of all, virtually every student noted the importance of doing long-range experimentation with elementary students. This in itself, is viewed as a remarkable and significant result of students conducting their own experiment in a methods course!

The most frequent response given was the importance of teaching kids that they have not failed if their experimental results are not what they expected. Another frequent response was the importance of kids being involved in the "creation" of the experiment from beginning to end and 19 students mentioned the importance of having students develop their own questions to investigate. Other responses included the importance of teaching the scientific method, the relevance of experimentation to real life, development of clear research questions, hypothesizing, observation skills, the concept of controls and variables, methods of reliable data collection, and basing conclusions on experimental evidence.

The developmental, testable, and creative nature of scientific knowledge were represented in student responses to how long-range experimentation should be conducted with elementary students. The most significant growth in understanding, as reported by students, related to the developmental nature of scientific knowledge. Twenty two responses related to this dimension of science, as compared to two

responses related to the creative nature and one response related to the testable nature of science.

Relationship of Qualitative and Quantitative Results

The relationship between increased understanding of the developmental, testable, creative, and unified nature of scientific knowledge, as reflected by qualitative and quantitative data was analyzed. There was a fairly significant increase in the understanding of the developmental nature of scientific knowledge as evidenced by the frequency of pre- and post-response data and the long-range follow up summary data. However, there was not a significant increase, revealed by these same data, of student understanding of the testable, creative, and unified nature of scientific knowledge. Thus, there is no strong correlation, with the exception of the developmental nature of scientific knowledge, between the statistically significant increase in student understandings as measured by the MNSKS and the results of the qualitative data analyzed.

It is important that the relationship between the quantitative and qualitative results be viewed in the context of the constructivist approach used to collect the qualitative data. Students were not asked on either the pre- and post-response or long-range experiment summary of learning, to relate what they learned specifically to the developmental, testable, creative, and unified nature of scientific knowledge. They were asked to respond to the open-ended questions of what is science?, how should science be taught at the elementary level?, what did you learn about scientific inquiry as a result of conducting the long-range experiment?, and what are your ideas about

how long-range experiments should be conducted with elementary students?.

Conclusions

With all that needs to be accomplished in the teaching of a one-semester elementary science methods course, instructors must be selective about what and how they will teach to best prepare students to teach science. Developing student understandings of the nature of science, while only one of many areas that need be addressed in a methods course, is an important area. The results of this study indicate that students begin their methods course with understandings of the nature of science which are largely incomplete.

The results of this study also indicate the potential of developing much more complete understandings about the nature of science as a result of integrating teaching strategies throughout the semester designed, in part, to develop such understandings. The students enrolled in the three sections of this elementary science methods course developed significantly greater understanding about the nature of science throughout the semester. While it was difficult to ascertain the extent to which each classroom experience had an affect on the growth of student understanding, there are some conclusions that can be drawn based on the results of the study.

The experience of conducting a long-range experiment had a significant impact on student understandings of and attitudes toward the nature of science. This experience also affected student understandings of and beliefs about the inclusion of topics directly-related to teaching elementary science. The positive correlation between the development of potential teachers' understanding of the

nature of science and the degree to which they included directly-related topics as important to teach in elementary science was evident in student pre- and post-semester responses, as well as the long-range experiment follow-up summary.

There was, however, a more marked increase in the development of student understanding of the nature of science, than there was in the increase of student responses which identified the importance of elementary teaching strategies related to the nature of science. The implication of these results for methods instructors is the importance of helping students to make explicit connections between what they learn and their conceptualization of teaching elementary science.

Another experience which contributed to the development of student understandings was the learning cycle lesson taught to peers during class. Additional data collected during the semester is currently being analyzed to further assess the degree and nature of impact the learning cycle had on student views about the nature of science and how science should be taught.

Two teaching strategies used in this study and believed to be important to develop student understanding about the nature of science, as well as relating this understanding to the teaching of elementary science, can be used and integrated with any topic taught or experience provided. The first of these strategies is student reflection. Asking students to reflect on their own learning and to place this learning in the particular context of the nature of science is important. Students will more likely be aware of their own learning as a result of the synthesis that occurs through their reflections.

The use of a constructivist approach is another method which can be integrated throughout the semester to help students develop understandings about the nature of science and teaching the nature of science. The value of this approach is that students truly develop an "understanding" of the nature of science. Through the use of more teacher-directed strategies, students would not as likely develop the level of understanding of the various inquiry processes and dimensions of the nature of scientific knowledge. There is also a much greater potential for students to develop scientific attitudes and values such as openness, objectivity, and belief in the value of science inquiry when a constructivist approach is used and first-hand experience with inquiry processes is provided.

Although the teaching strategies and approaches discussed in this paper have not provided the level of understanding the nature of science held by research scientists (and science teacher educators), they do provide a sound foundation upon which students can continue to develop their understandings. These newly acquired understandings, in turn, increase the potential that these prospective teachers will help their own students develop understandings and beliefs related to the nature of science.

References

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Appendix A

LONG RANGE GROUP PROJECT

Purposes of the Assignment

1) Gain personal experience in the use of scientific processes to generate knowledge about a particular scientific question;

2) Analyze your effort to conduct a scientific experiment in the contexts of what you have learned about:

   A) the nature of scientific knowledge,

   B) teaching the nature of scientific knowledge to elementary students, and

   C) planning an experience for elementary students to conduct research experiments;

3) Gain experience working as a member of a cooperative group to conduct a scientific experiment and to analyze this experience in the context of organizing cooperative group activities for elementary students.

Guidelines for Writing the Research Report

1. Include a cover page with the following information: Title of your project, names of group members, and course section.

2. Research question - State, in specific terms, the question your group is investigating.

   Example question - How does natural light affect the quality and direction of African violet plant growth? (As opposed to "How does light affect plant growth?)

3. Hypothesis - State the "educated guesses" of group members in regard to the answer to the research question. **NOTE** that your group does not have to reach consensus about the hypothesis. State different hypotheses of group members and identify by member's name.

   Example hypothesis to above question - The presence of natural light has a positive effect on the quality of African violet plant growth and will cause the plant to grow in the direction of the light source.

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4. Materials - List all materials and amounts/number of materials used to conduct the experiment.

5. Procedure - List, step by step, the following information:

   A. how you set up the experiment, identifying the control conditions and variable conditions of your experiment.
   B. method you used to collect and record data.

   * Procedures should be written clearly enough so that other "scientists" could easily conduct the same experiment by reading about the procedures used by your group.

6. Record of Data Collected - Include all data collected during the experiment, in an easy to interpret form. This form could be a table, graph, organized notes, photographs, or a combination of these. The more organized your data is, the easier it will be for you to interpret this data and draw conclusions from your results. Be as specific as possible in your descriptions; for example, data collected to determine the affect of natural light on plant growth, should be stated in terms of before and after height of plants, number of leaves, coloration of leaves, number of blossoms, etc.

7. Results - Write a narrative which describes the data collected throughout the experiment. Information presented in table, graph, and photograph form should be interpreted for the reader.

. Conclusions:

   A. Begin this part of the report by stating whether the hypothesis/hypotheses was accepted or rejected.
   B. State the reasons for accepting or rejecting each hypothesis.
   C. Explain what the "research community" can learn from the results of your experiment, in regard to the research question you investigated. This learning may relate to the contribution of your results to the scientific knowledge base associated with your research question and/or the procedures used to conduct the experiment.
   D. Include any research questions which your group would recommend for follow-up or future research about the same topic or similar topics.

9. Bibliography - List any references that were used to help you conduct any step of the experiment (question, hypothesis, procedure, or conclusions). Cite these references within your report.

10. Role of Each Group Member - List all tasks associated with this assignment and which group member(s) were responsible for these tasks. The signature of all group members, indicating agreement must be present on this part of the assignment. It is the groups' responsibility to ensure that the work is distributed as equally as possible. A group grade will be assigned.

Table 1
Reliabilities of the MNSKS
N=68

Scale	No. of Items	Coefficient Alpha
Developmental	8	.69
Testable	8	.71
Creative	8	.83
Unified	8	.68
MNSKS	32	.76

Table 2

Mean Scores on Pre- and Post-Measures of the MNSKS

Scale	Pre-Test (N=76)	Post-Test (N=68)
Developmental	32.14	33.26
Testable	29.71	31.38
Creative	30.16	32.51
Unified	33.84	35.16
MNSKS	125.85	132.32

Table 3

Paired-Comparison T-Test for the MNSKS Pre- and Post-Test
N=67

Variable	Mean	STD Error	T PROB
Developmental	1.31	0.38	0.0009
Testable	2.03	0.53	0.0003
Creative	2.30	0.56	0.0001
Unified	1.39	0.39	0.0007
MNSKS	6.49	1.19	0.0001

Table 4

Long-Range Experiment
Frequency of Student Responses Related to the Nature of Scientific Knowledge

N=73

Dimension of Scientific Knowledge	No. Of Responses
Developmental	47
Testable	4
Creative	3
Unified	1
*Parsimonious	4

* Not a defined component of scientific knowledge in this paper

Table 5

Long-Range Experiment
Student Learning About Science Inquiry
N=74

Science Inquiry	No. of Responses
Research Question	
Generates more questions	11
Importance of clear question	5
Hypothesizing	
Can learn from rejection of hypotheses	40
Importance of hypothesizing	7
How to hypothesize	3
Experimental Design	
Importance of controlled variables	12
Difficulty of controlling variables	6
Importance of observation and recording of data	6
Conclusions	
Validity issues	5
Base conclusions on evidence	1
Combined product of product, process, and attitudes	1
Affective Components	
Amazement that not everything turns out like you expect	3
Discouragement from rejected hypothesis	2
Frustration by inconclusiveness	1
Role of sincere interest; sense of wanting to discover outcome	1
Acceptance of ambiguity and taking a positive approach to "failure"	1

Figure 1

Long-Range Experiment

Student Learning About the Nature of Science

Example Responses

The inquiry process generates more questions.

Having an open-mind about experimental results is important.

The inquiry process is a never-ending search for knowledge.

The usefulness of the steps of the scientific method is evident.

The meaning of trail and error in science is more clear.

Conclusions are often inconclusive and lead to other questions, hypotheses, and experiments.

Results can change each time you do an experiment.

When an experiment has been done many times, you should still say that the results "indicate" that....

Repeating experiments is important to get valid results.

Hypotheses are never wrong, they're just not supported by results.

Experiments don't fail - you learn from results.

The results of an experiment don't "prove" anything.

Inquiry involves creative thinking.

Science experiments can and should be simple.

The simplest of experiments can yield much information.